

Statement Submitted to
Environmental Protection Agency
for the
Public Meeting, February 22, 1978, San Francisco
Regarding
MODIFICATION OF SECONDARY TREATMENT REQUIREMENTS
by
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1. Although prior commitments prevent me from attending the public meeting, I wish to submit this statement for the record on the question of waivers for secondary treatment according to Section 301(h) of the 1977 Clean Water Act. In past years I have participated in the design of most of the major outfalls along the California Coast and at Honolulu as a special hydraulics consultant and am presently so engaged for the City and County of San Francisco (as a special consultant to the firm of CH₂M Hill).

At Caltech I have been involved in research on dispersion and mixing of wastewater discharges, and am presently Director of the Environmental Quality Laboratory, an interdisciplinary policy study center for environmental problems.

However, my comments are given here as an individual and not as representing either Caltech or any of the sewerage agencies.

2. The principal technical reason for having a waiver provision for secondary treatment for municipal discharges is that for some outfall systems the dilution is so high that very good ambient water quality can be achieved with less than secondary treatment. Therefore, the criteria for a waiver of the secondary treatment requirement must give

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full consideration to the dilution obtained by the outfall system. In a high performance outfall diffuser, such as those used by major dischargers in California and Hawaii, initial dilutions are typically 100:1, and may range up to 1000:1 in very favorable circumstances.

3. The dilution for an outfall system is achieved in stages which can be designated as initial dilution and subsequent field dilution. The initial dilution is that which occurs immediately in the vicinity of the outfall diffusion structure as the result of the buoyancy and momentum of the discharge fluid during the first few minutes after discharge. The mixing process in this phase is determined by the kinetic and potential energy of the discharge itself. The subsequent field dilution, however, occurs as a result of natural oceanic turbulence as the sewage plume drifts away from the discharge site. For engineering and regulatory purposes, it is better to consider just the initial dilution as has been done by the State of California because: a) it is much larger than the subsequent dilutions for a well designed outfall diffuser; b) it is more predictable; c) it is more easily measured; d) it is under the control of the design engineer.

The initial dilution is determined by the characteristics of the diffuser (overall length, number of ports, diameter of ports and orientation of ports and overall diffuser structure; depth of water; the ocean currents; and water column density stratification).

Typical diffuser geometry and depths for major west coast outfalls have been tabulated by Koh and Brooks (see Reference 1 and Table 1). The effect of all of the parameters above (diffuser geometry, depths, currents and stratifications) are explained in that same paper. Additional information on modeling is given in References 2, 3, and 4. The state-of-the-art is now such that it is possible to measure dilution in the field as well as to simulate it by computer model as has been done for the design of major California and Hawaii outfalls. Like other

Table 1 Summary of characteristics of major Pacific Ocean outfalls (USA)

	Year Operation Began	Pipe Diameter (inside) (inches)	Length of Main Outfall (excl. diff.) (ft)	Length of Diffuser L_d (ft)	Depth of Discharge (ft) (nominal)	Design Average Flow Q (ft ³ /sec)	Port Diameters ^a (inches)	Port Spacing (average) ^c (ft)	Velocity of Disch. (nominal) for ave. flow (fps)	Q/L_d (ft ² /sec)	Area Factor (Total Port Area/Pipe Area)
Sanitation Districts of Los Angeles County											
Whites Point No. 3	1956	90	7,900	2,400	200-210	232	6.5-7.5	24	8	0.097	0.63
City of Los Angeles at Hyperion	1960	144	27,525	7,920	195	651	6.75-8.13	48	13	0.082	0.44
San Diego	1963	108	11,500	2,688	200-210	363	8.0-9.0 ^b	48	15	0.135	0.39
Sanitation Districts of Los Angeles County											
Whites Point No. 4	1965	120	7,440	4,440	165-190	341	2.0-3.6	6	9	0.077	0.51
Metrop. Seattle (West Point)	1965	96	3,050	600	210-240	194	4.5-5.75	3	6	0.323	0.60
Sanitation Districts of Orange County, Calif.											
	1971	120	21,400	6,000	175-195	450	2.96-4.13	12	13	0.075	0.45
Honolulu (Sand Island)	1975	84	9,120	3,384	220-235	164	3.00-3.53	12	10	0.048	0.44

^a Exclusive of end ports, which are usually somewhat larger.^b Blocked by orifice plates with openings of 6.5-7 inches for early years' low flow.^c Length of diffuser divided by number of ports; real spacings on each side of the pipe are twice the values indicated.

Source: Koh and Brooks, "Fluid Mechanics of Waste-Water Disposal in the Ocean", Annual Review of Fluid Mechanics, Vol. 7, 1975, p. 192.

water quality measures, the dilution is a quantity which varies in time and space; hence, for setting criteria or regulations, the frequency distribution of dilution must be considered. For further discussion of this matter see Reference 5 and Attachment 1.

4. The first question raised by the EPA pre-meeting document (on page 4) (regarding the first criterion) is what to use as "applicable water quality standard specific to the pollutant to which the modification is requested". Since the key technical idea behind the waiver provision is high dilution in ocean waters, the appropriate effluent limits should be derived from ambient water quality standards by a back calculation based on dilution. If ambient dissolved oxygen is used as an ambient water quality parameter, then it may be inferred what BOD increment is allowable after dilution, and then by multiplying by the dilution the effluent BOD limit is obtained. For example, if the BOD of the mixture after initial dilution is to be kept less than 1 mg/l and the dilution is 150, then the effluent could have up to 150 mg/l of BOD.

This approach of deriving effluent limits by a back calculation from ambient limits has recently been adopted in California's Revised Ocean Plan (Reference 6) for toxic materials ("Table B") after extensive study. This same approach can logically be applied to all pollutants.

5. In regard to the second criterion, the evaluation of water quality should be made without regard to what the impact would be if secondary treatment were to be provided. Using secondary treatment as a reference point is not logical because it does not relate to ambient water quality objectives nor the performance of outfalls.

6. For the criterion 4, I recommend that the concentration of toxic substances be limited to values which are required to protect the environment, such as done in Table B of the California Revised Ocean Plan. The derived effluent limits depend on the dilution achieved.

The concentration values which would occur after secondary treatment (if done) are unsatisfactory reference points because they depend on the degree of source control; they do not reflect the dilution capabilities of an outfall; and they do not necessarily assure environmental protection.

7. In summary, I urge EPA to develop waiver criteria in which outfall dilution is fully considered as part of the treatment-disposal system. Effluent limits can be back calculated from ambient water quality parameters outside the zone of initial mixing. The methodology exists for both predicting and measuring dilutions to satisfactory levels of accuracy for using dilution in regulatory matters.

REFERENCES

1. Koh, R. C. Y., and N. H. Brooks, "Fluid Mechanics of Waste-Water Disposal in the Ocean," Annual Review of Fluid Mechanics, Vol. 7, 1975, pp. 187-211.
2. Brooks, N. H., "Dispersion in Hydrologic and Coastal Environments," W. M. Keck Lab. Report KH-R-29, California Institute of Technology, December 1972, 136 pp. (Also Environmental Protection Agency, Ecological Research Series, EPA-660/3-73-010, August, 1973.)
3. Koh, R. C. Y. and L.-N. Fan, "Mathematical Models for the Prediction of Temperature Distribution Resulting from the Discharge of Heated Water into Large Bodies of Water," EPA Water Pollution Control Research Series Report No. 16130DW010/70, 1970.
4. Baumgartner, D. J., D. S. Trent, and K. V. Byram, "User's Guide and Documentation for Outfall Plume Model" (Working Paper #80, EPA Pacific Northwest Water Laboratory), 1971.
5. Isaacson, M. S., R. C. Y. Koh, and N. H. Brooks, "Sectional Hydraulic Modeling Study of Plume Behavior: San Francisco Southwest Ocean Outfall Project," W. M. Keck Laboratory of Hydraulics and Water Resources, California Institute of Technology, Technical Memorandum 78-2, January 1978.
6. California State Water Resources Control Board, Water Quality Control Plan for Ocean Waters of California, January 1978 revision.

APPENDIX A

DEFINITIONS AND INTERPRETATIONS OF DILUTION*

The purpose of this appendix is to clarify the meaning and use of the concept of dilution of sewage in sea water. Dilution is one of the most basic measures of performance of an outfall diffuser, and is often mentioned in regulatory documents.

1. Basic Meaning of Dilution

The dilution usually is defined as

$$S = \frac{\text{total volume of a sample}}{\text{volume of effluent contained in the sample}} \quad (1)$$

The reciprocal of S is thus equal to the volume fraction of effluent in a sample, designated p ,

$$\begin{aligned} p &= 1/S = \text{volume fraction of effluent, or} \\ &= \text{relative concentration} \end{aligned} \quad (2)$$

The term relative concentration is used to indicate that $p = 1$ for undiluted effluent ($S = 1$) and $p = 0$ ($S = \infty$) for pure ambient water. In between these limits, the mixture contains p parts of effluent and $1 - p$ parts of ambient water.

Alternatively some writers¹ and agencies² use a dilution D defined as

$$D = \frac{1-p}{p} = \frac{\text{volume of ambient water in the sample}}{\text{volume of effluent in the sample}} \quad (3)$$

By definition, also

$$D = S - 1 \quad (4)$$

By rearranging (3), we find

$$p = \frac{1}{D+1} \quad (5)$$

*This is a slightly revised version of a memorandum to CH₂M Hill from N. H. Brooks, dated December 13, 1977 (exclusive of Secs. 7 and 8 in that memo).

Because hydrodynamic models yield relative concentrations (p), it is more convenient to use S rather than D .

Furthermore, ecological effects are all related to concentration c of a particular contaminant X . Defining

c_s = background concentration of substance X in sea water

c_d = concentration of X in the effluent discharge

it follows that

$$S = \frac{c_d - c_s}{c - c_s} \quad \text{or} \quad p = \frac{c - c_s}{c_d - c_s} \quad (6)$$

$$c = c_s + \frac{1}{S} (c_d - c_s) = c_s + p(c_d - c_s) \quad (7)$$

In simple terms, the increment of concentration above background is reduced by the dilution factor (or multiplied by p) from the point of discharge to the point of measurement of c . The ambient concentration is noted to be a simple linear function of p for any given discharge plume.

2. Variation of p in time and space

The relative concentration p may actually be described at a point by allowing the sample volume V mathematically to approach zero as a limit (in fact we stop at V still large compared to individual molecules!). Since effluent plumes are turbulent and variable depending on the rate of discharge, the current speed and direction, and the density profiles, we may write

$$p = p(x, y, z, t) \quad (8)$$

to indicate that in general p is a function of spatial coordinates (x, y, z) and time (t) .

3. Averaging Procedures

The relative concentration function p is not convenient to work with

in all its detail; we must consider averages of several kinds as follows:

a. Time average of p

$$\bar{p}_t(x, y, z, t_o) = \frac{1}{T} \int_{t_o}^{t_o+T} p(x, y, z, t) dt \quad (9)$$

This average is still a function of position, the averaging time T and the initial time t_o . However, if the plume turbulence is of time scales much less than T then the resulting \bar{p}_t is a slowly varying function, reflecting only the change of flow rate and ocean conditions (over hours) rather than short-duration turbulence-induced fluctuations (of the order of minutes or seconds).

b. Spatial average of p

$$\bar{p}_V(x_o, y_o, z_o, t) = \frac{1}{V} \iiint_V p(x, y, z, t) dV \quad (10)$$

We generally consider the averaging volume to be relatively small such as the size of a grab sample, with coordinates (x_o, y_o, z_o) indicating the location of the center of the volume V . This kind of average wipes out turbulent fluctuations occurring on scales smaller than $V^{1/3}$.

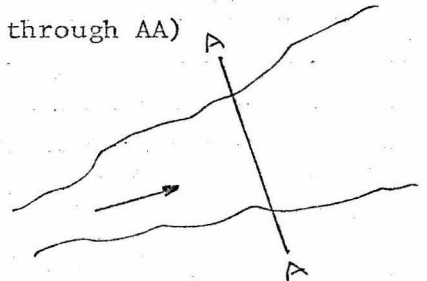
c. Flux average of p^*

For a plume or sewage field passing a given cross-section AA a flux-average (\bar{p}_f) may be defined as:

Flux of sewage through AA = \bar{p}_f · (flux of water through AA)

$$\int_A p u dA = \bar{p}_f \int_A u dA$$

$$\text{or} \quad \bar{p}_f(t) = \frac{\int_A p u dA}{Q} \quad \text{where} \quad Q = \int_A u dA \quad (11)$$



The area of integration A is the area occupied by the plume in the cross-section, with the edges defined to occur at some small threshold level

*In the body of this paper the flux average is called the flow-weighted average.

of p . Basically the flux-average of p is the value to be multiplied by the total plume flow.

The flux average may also be thought of as a spatial average where V is the volume of plume water that passes a given cross-section in a unit of time. It is much more convenient than the true spatial average because it's practically impossible in the ocean to measure the concentration at many different locations at the same instant.

d. Average for a group of samples. If N bottle samples are taken, each with volume V_i , $i=1\dots N$, and measured p_i , then

$$\bar{p} = \frac{\sum_{i=1}^N V_i p_i}{\sum_{i=1}^N V_i} = \frac{\text{total effluent volume}}{\text{total volume}} \quad (12)$$

This is the same value that would be obtained if all samples were mixed together in a large container.

e. Average dilution. Because the dilution is defined basically as the reciprocal of the relative concentration p , then the dilution of a composite sample is, according to equation (12),

$$\bar{S} = \frac{\text{total volume}}{\text{total effluent volume}} = \frac{1}{\bar{p}} \quad (13)$$

By equations (12) and (2)

$$\bar{S} = \frac{\sum_{i=1}^N V_i}{\sum_{i=1}^N V_i \frac{1}{S_i}} \quad (14)$$

Equation (14) shows that dilutions should be averaged harmonically in order to get the proper value to describe a composite. Therefore, we adopt the following mathematical definitions for average dilution

$$\text{Time average} \quad \bar{S}_t = \frac{1}{\bar{p}_t} \quad (15)$$

$$\text{Spatial average} \quad \overline{S}_v = \frac{1}{\overline{p}_v} \quad (16)$$

$$\text{Flux average} \quad \overline{S}_f = \frac{1}{\overline{p}_f} \quad (17)$$

where \overline{p}_t , \overline{p}_v , and \overline{p}_f are given by equations (9), (10), and (11).

It is not appropriate to average dilutions directly because $S \rightarrow \infty$ at the edge of the plume, and all arithmetic averaging procedures will give unreasonable or infinite results. Gibson³ has addressed this difficulty and devised a procedure for weighting the dilution with the fraction of effluent; conceptually this yields the same result as Eq. 14⁴.

4. Sampling in Field and Laboratory

In the ocean, a grab sample is an instantaneous sample averaged over a relatively small volume. A succession of grab samples at the same place yields a time average, often over many days or months. Or, a pumped sample from a given location in a plume gives a time-average at a point (for the length of time required to take the sample).

In the plume behavior studies in the Keck Hydraulics Laboratory, the dilutions were measured in samples withdrawn through small sample tubes over a period of approximately one to two minutes (corresponding to the order of 10 minutes in the ocean). These lab values are distinctly different from grab samples one would take in the ocean, because the latter would show more sample fluctuation because of the absence of the time-averaging over small scale turbulent fluctuations. In the Keck Laboratory in an earlier study, Wright⁵ measured relative concentration with a tiny electrical conductivity probe with characteristic times of only a few 1/100's of a second. He found instantaneous concentration maxima in the range of 1.5 to 4 times the local mean values, with a few scattered observations giving factors up to 6. Gibson⁶ has recently done some similar intensive small scale sampling in the ocean in the vicinity of sewer outfalls.

Flux-averaging is difficult to accomplish in the field, and in

the lab it can only be done by measuring both concentration and velocity profiles across a plume.

5. Mathematical models

In the usual plume models (e.g., Brooks⁷), the relative concentrations, p , (or "tracer concentrations") are some of the quantities calculated from the equations of conservation of mass, momentum, and energy fluxes for a buoyant jet. They are time-averaged values (which therefore do not represent the turbulent fluctuations at the plume scale). Dilutions are calculated as the reciprocals of p values.⁸

The maximum time-averaged concentration in any cross section in a plume usually is the centerline (or axial) value, and correspondingly gives S_{cl} , the minimum time-averaged dilution in any cross section. The math models also conveniently give flux averages \bar{p}_f and \bar{S}_f .

Neither the centerline nor flux-average dilutions are easy to measure in the ocean. However, the computed minimum or centerline dilution is approximately comparable to the average of a group of samples from the central part of a rising plume (up to the completion of the initial mixing phase); and the flux-average dilution is comparable to the average dilution of samples from a vertical profile through the flow-away zone (after initial mixing due to buoyancy and momentum of the jet source). (Henceforth, whenever the term "average dilution" is used, it means harmonic average as in equation (14).) Furthermore, the computed minimum dilution for a plume should be approximately the same as the minimum in the vertical profile (time-averaged) through the sewage field in the flow-away zone.

6. Time and Length Scales

Since there are different physical processes operating at different time and length scales, there is no universal or overall mathematical model. Instead, the prediction procedure involves two major parts:

(1) Initial mixing phase, wherein the mixing and dilution are caused by the momentum and buoyancy flux of the discharge jet. The plumes may be bent over by the ambient current, thus increasing the

plume dilution. All of these models are based on time-averaged point concentrations over short time scales T_1 (minutes), and then flux averaged over scales L_1 (the width of the rising plumes near the top of their height of rise). The term initial dilution (as used by the outfall design group at CH₂M Hill) is defined as the flux-averaged, time-averaged dilution (averaged over the plume scales T_1, L_1) achieved at the completion of the initial mixing phase including the effects of discharge flow rate, density structure, and ambient currents. The State of California Water Resources Control Board presumably uses the same definition of initial dilution in its revised Ocean Plan² with the exception that no benefit is taken for the effect of ocean currents in increasing dilution (i.e., currents are presumed to be the order of 0.1 knot, which is enough to gradually flush the region but does not effect the dynamics of initial dilution).

The initial dilution thus defined is still a slowly varying function of time (at time scales $T_2 \gg T_1$) in response to varying sewage discharge, ocean stratification and currents. However, in modeling calculations, the flow is considered quasi-steady, i.e., these changes do not affect the dynamics at time scales T_1 .

(2) Field process. In subsequent hours and days (longer time scales than T_1), a variety of physical, chemical, and biological processes come into action, such as: advection by currents, turbulent diffusion and shear dispersion, upwelling, sedimentation; oxygen uptake by BOD, other chemical reactions, flocculation; bacteria and virus disappearance (dieoff, sedimentation, ingestion), biostimulation, bioaccumulation, etc. These phenomena take place over a wide area, at scales $L_2 \gg L_1$. It is no longer useful to make time or volume averages of concentrations (or dilutions) because the sewage field location is highly variable, being better described by probabilities. In other words, a certain point in the ocean, away from the outfall diffusers, may be inside the drifting sewage field only 5% of the time, and concentration would be 0 for the 95% of the time. Clearly then, an overall average is not useful (including 95% of zeros). Consequently, flux-averaged concentrations or dilutions are computed only for points inside the plume (wherever it might be), coupled with probability

estimates of how frequently the plume occurs at various places under various conditions (like the shoreline in wet weather).

References and Footnotes to the Appendix

1. Gibson, C. H., "Evaluation of Initial Dilution for Ocean Discharges," Draft Report to California State Water Resources Control Board, September 1977.
2. California State Water Resources Control Board, Proposed Amendments to Water Quality Control Plan for Ocean Waters of California, December 1977 Draft.
3. Gibson, C. H., *ibid.*
4. For example, for a group of samples of equal volume, \bar{D} may be determined as followed by Gibson's procedure

$$\bar{D} = \frac{\sum_{i=1}^N p_i D_i}{\sum_{i=1}^N p_i} = \frac{\sum_{i=1}^N p_i \frac{1-p_i}{p_i}}{\sum_{i=1}^N p_i} = \frac{\sum_{i=1}^N (1-p_i)}{\sum_{i=1}^N p_i}$$

using equation (3). Since there are N samples, $\sum_{i=1}^N 1=N$,

$$\bar{D} = \frac{N}{\sum_{i=1}^N p_i} - 1 ,$$

and using equations 12 and 13, we obtain

$$\bar{D} = \frac{1}{\bar{p}} - 1 = \bar{S} - 1$$

which is consistent with equation (4).

5. Wright, S. J., "Effects of Ambient Crossflows and Density Stratification on the Characteristic Behavior of Round Turbulent Buoyant Jets," W. M. Keck Lab. Report KH-R-36, California Institute of Technology, May 1977, 254 pp.
6. Gibson, C. H., *ibid.*
7. Brooks, N. H., "Dispersion in Hydrologic and Coastal Environments," W. M. Keck Lab. Report KH-R-29, California Institute of Technology, December 1972, 136 pp.
8. Since all values are time-averaged in math models, the overbars denoting averaging are omitted in the technical literature.